REPORT #
RRTAC 87-5

Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta

THE COAL ASSOCIATION OF CANADA

Heritage Fund

Alberta

LAND CONSERVATION AND RECLAMATION COUNCIL
Reclamation Research Technical Advisory Committee

Report No. RRTAC 87-5

REVIEW OF THE SCIENTIFIC BASIS OF WATER QUALITY CRITERIA FOR THE EAST SLOPE FOOTHILLS OF ALBERTA

by

BEAK ASSOCIATES CONSULTING LTD.

Prepared for

The Mountain Foothills Reclamation Research Program (MFRRP)

of

THE LAND CONSERVATION AND RECLAMATION COUNCIL

(Reclamation Research Technical Advisory Committee)

and

THE COAL ASSOCIATION OF CANADA

1987

STATEMENT OF OBJECTIVE

The recommendations and conclusions in this report are those of the authors and not those of the Alberta Government or its representatives.

This report is intended to provide Government and Industry staff with up-to-date techncial information to assist in the development of guidelines and operating procedures. The report is also available to the Public so that interested individuals similarly have access to the best available information on land reclamation topics.

ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from the Department of the Environment and two Deputy Chairmen from the Department of Forestry, Lands and Wildlife. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The Reclamation Research Program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the Research Program, the Council appointed the Reclamation Research Advisory Committee (RRTAC). The Committee first met in March 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands and Wildlife, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and coordinating body for Reclamation Research.

Additional information on the Reclamation Research Program may be obtained by contacting:

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Additional copies may be obtained from:

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RECLAMATION RESEARCH REPORTS

** 1. RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp.

DESCRIPTION: This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

** 2. RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi, and H.F. Regier. 160 pp.

DESCRIPTION: Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

N/A 3. RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker, and P.F. Polster. 2 vols, 541 pp.

DESCRIPTION: Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their fitness for use in Reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

N/A 4. RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp.

DESCRIPTION: This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

N/A 5. RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stien, R. Leitch, and G. Lutwick. 253 pp.

DESCRIPTION: Presents nine technical papers on the chemical, physical and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites and use of ash as a soil amendment. Workshop discussions and summaries are also included.

N/A 6. RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp.

DESCRIPTION: Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system. Vol. 2 comprises the keyword index and computer access manual.

N/A 7. RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp.

DESCRIPTION: This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available from the Alberta Environment Library.

N/A 8. RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp.

DESCRIPTION: Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

N/A 9. RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp.

DESCRIPTION: Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

N/A 10. RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz. 123 pp.

DESCRIPTION: Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics and resulting water quality. Mitigative measures and priorities were also discussed.

N/A 11. RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp.

DESCRIPTION: This is a review and analysis of information on planting stock quality, rearing site preparation, planting and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

*** 12. RRTAC 84-1: Land Surface Reclamation: A Review of International Literature. H.P. Sims, C.B. Powter, and J.A. Campbell. 2 vols, 1549 pp.

DESCRIPTION: Nearly all topics of interest to reclamation including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

** 13. RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp.

DESCRIPTION: This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

* 14. RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 15. RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser, and J.C. Zak. 2 vols, 676 pp.

DESCRIPTION: This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

** 16. RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz. 416 pp.

DESCRIPTION: Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

* 17. RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 18. RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp.

DESCRIPTION: The report examines the critical issue of settling pond design and sizing and alternative technologies.

** 19. RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp.

DESCRIPTION: Reconstructed soils representing different materials handling and replacement techniques were characterized and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

* 20. RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp.

DESCRIPTION: In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

** 21. RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp.

DESCRIPTION: This report summarzies the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

** 22. RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Program. A. Maslowski-Schutze. 71 pp.

DESCRIPTION: This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

* 23. RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp.

DESCRIPTION: The report deals with the availability of water supply in or beneath cast overburden at the Battle River Mining area in east-central Alberta to support post-mining land use. Both groundwater quantity and quality are evaluated.

* 24. RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp.

DESCRIPTION: This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

* 25. RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 26. RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp.

DESCRIPTION: This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed.

** 27. RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp.

DESCRIPTION: Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual included provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

** 28. RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik, and D.G. Walker. 174 pp.

DESCRIPTION: This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area.

** 29. RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (compiler). 218 pp.

DESCRIPTION: Technical papers were presented which describe: the mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

* 30. RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

Available from: Publication Services
Queen's Printer
11510 Kingsway Avenue
Edmonton, Alberta T5G 2Y5

* A $5.00 fee is charged for handling and postage.
** A $10.00 fee is charged for handling and postage.
*** A $20.00 fee is charged for handing and postage.
N/A Not available for purchase but available for review at the Alberta Environment Library, 14th Floor, 9820-106 Street, Edmonton, Alberta T5K 2J6.

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ACKNOWLEDGEMENT

We would like to acknowledge the assistance of Dr. Theo Beukeboom, Mr. Marlin Murphy and Mr. Walter Nahulak in the preparation of this report. Their direction and guidance were much appreciated. We would also like to thank the MFRRP reviewers for their thoughtful criticisms and suggestions.

EXECUTIVE SUMMARY

The study was commissioned to establish the scientific rationale for existing wastewater discharge legislation for Alberta East Slopes coal mines. Three water quality parameters - total suspended solids, pH and total iron - and four design flow parameters - applicability of the dam and canal safety guidelines, the two effluent water quality exemptions for 10 year 24 hr. precipitation events, and the "no-discharge" requirement for surface runoff from facilities and for tailings ponds were considered. Data sources for the review included: world scientific literature, relevant federal (Canada and U.S.A.), provincial, territorial and state legislation, available background water quality data, and personal communications from coal company and regulatory personnel.

Total Suspended Solids (TSS)

TSS is highly variable within the East Slopes and increases are associated with seasonal events (e.g. snowmelt) and local precipitation events. A wide range in settling pond performance also occurs. Current Alberta guidelines for wastewater are the larger of either a maximum of 50 mg/L or 10 mg/L above background. Guidelines in other areas differ considerably from both Alberta and each other. The source of the Alberta guidelines was an intermediate value between the U.S. EPA daily maximum and 30-day average guidelines.

Available scientific literature suggests that TSS concentrations of 25 mg/L or less have no harmful effects on fisheries, and concentrations of 25 - 80 mg/L have little effect. Since these are average concentrations, the effects of short term events would presumably be less. Differences in settleable/non-settleable fractions and the type of solids may alter these effects, but insufficient data exists for setting standards. The current Alberta guidelines appear adequate for environmental protection. However, Alberta coal mine operators are expected to continue to have some difficulty in meeting the guidelines and some revision in the guidelines is possible. It is recommended that:

1. Studies be carried out to examine the settleable/non-settleable relationship in settling pond and background solids.

2. Quantitative studies of the environmental effects of the two solid fractions be conducted.

pH

East Slope waters are mildly alkaline, as are waters released from mine wastewater settling ponds. The Alberta guidelines (pH 6.5 - 9.5) differ slightly from other guidelines which call generally for pH 9.0 or less as a maximum. The source of the Alberta guidelines was based on professional opinion.

World scientific literature suggests that a pH range of 6.0 to 9.0 offers complete protection of aquatic life. The Alberta guideline was felt to be slightly high and it was recommended that the guideline be amended to pH 6.5 - 9.0.

Total Iron

In general, iron showed a wide variation in concentration. Iron concentrations in settling pond effluent were on occasion greater than the natural range. The Alberta guideline for iron is 3.5 mg/L and is more stringent than current U.S. EPA guidelines but less stringent than other Canadian guidelines. The source for the guideline was a modification of an earlier U.S. EPA requirement.

The validation data for the guidelines suggest that 0.3 mg/L may be an appropriate level for the protection of aquatic life. Based on these data, the current Alberta guideline was considered potentially too high, but further research is required before the guideline can be changed. Specific recommendations include:

1. The iron parameter (e.g. total, extractable) measured should be better defined.

2. The actual toxicity of individual iron forms in minewater effluents should be determined.

3. A procedure is required to define reasonable mixing zones in the receiving stream environment.

Dam and Canal Safety Guidelines

A detailed set of dam design criteria are established under the guidelines. No comparable federal guidelines exist, and the Alberta guidelines are equally or more restrictive than other provincial or state guidelines. The Alberta guidelines are based on professional judgement and felt by Alberta Environment to be too conservative. The Department is currently working on improving the criteria. The Coal Association is recommended to input into these revisions.

Precipitation Exemption

The current guidelines for TSS, pH and iron are currently waived in the event of a 10 year, 24 hr. storm. A wide range of approaches are used by other agencies, and the current Alberta guideline is based on the U.S. EPA exemption. The 10 year, 24 hr. storm specification has been standard in the U.S. over the past decade.

Alberta coal mine operators are frequently unable to meet TSS guidelines for storm events less than the 10 year 24 hour guideline. While this may be due to the inability of the guidelines to deal with antecedent moisture conditions (e.g. percent saturation of the watershed), it was not recommended that the guidelines be altered since they would become excessively complex. Review of the TSS guidelines, plus the collection of more complete hydrological and meterological data at mine sites prior to operation was recommended.

Duration of Precipitation Exemption

The guidelines do not specify the duration of the 10 year 24 hour precipitation exemption, but current practice by Alberta Environment is to allow 48 hours. Guidelines in other regions include case-by-case assessments, and exemptions based on watershed response and settling pond retention times to a maximum of 36 hours. The Alberta guideline avoids these complexities by setting a single, relatively large value, and appears adequate. However, it was recommended that

the 48 hour exemption be extended to also include the period of continuous rainfall following the 10 year, 24 hour storm event. It was also recommended that the 48 hour period be specified in the guideline.

<u>No-discharge Requirements and Exceptions</u>

Discharge from plant site surface facilities and from tailings ponds are permitted in the event of a 10 year, 24 hour and a 20 year, 24 hour storm event, respectively. In general, no-discharge design of tailings ponds is also encouraged in other regions. The rationale for no-discharge appears to be the possible presence of toxicants in tailings ponds not found in other mine wastewaters.

General practice in Alberta is for plant site runoff to be treated as general surface runoff and discharged. It was recommended that the no-discharge requirement for plant site runoff be removed from the guidelines. The no-discharge requirement for tailings was considered difficult to meet and unrealistic. Since quality of tailings water is often good, it was recommended that periodic, controlled discharge of tailings water be allowed, provided appropriate water quality standards are met. Such a change will require development of tailings water quality guidelines plus site specific license requirements.

1.0 INTRODUCTION

1.1 Background

In 1983, a joint industry/government Mountain-Foothills Reclamation Research Program (MFRRP) was initiated. This program involved three subcommittees to conduct research in revegetation, materials handling and hydrology. The hydrology subcommittee completed a manual titled "A Critical Analysis of Settling Pond Design and Alternative Technologies" (Phase 1) in 1985 (Monenco 1986). Funding was provided equally by the Heritage Trust Fund and the Coal Association of Canada.

Phase II of the hydrology program (Fall of 1986) is to complete a thorough assessment of the standards which apply to the wastewater effluents on a minesite. The purpose of the study is to determine if the environmental protection set by guidelines is supported by the available scientific information and what modifications may be appropriate.

In examining the environmental guidelines for mine wastewaters, the study has synthesized world literature on the potential environmental effects of the contaminants identified in the Alberta guidelines. These data are then reviewed within the context of the Alberta East Slopes environment and the current mining operations. In this way, the recommendations made are designed to be directly applicable to Alberta East Slope coal mining operations.Unlike the Phase I study (Monenco 1986), this report does not examine treatment alternatives in detail.

1.2 Current Coal Mining Operations

Five companies currently operate coal mines in Alberta's East Slope foothills and mountain regions (Table 1.1). A number of firms have plans for future mining operations in the East Slopes, but have not been listed since it is not possible to

Table 1.1 **Coal producers of the Alberta East Slope.**

Company Name	Mine Name	Type of Operation	Use of Coal	Location	Watershed
Smoky River Coal Ltd.	Smoky River	combined surface and underground	10% thermal 90% metallurgical	Grande Cache	Smoky River
Obed Mountain Coal Co.	Obed Mountain	surface	thermal	Hinton	Athabasca River
Cardinal River Coals Ltd.	Cardinal	surface	metallurgical	Luscar	McLeod River
Luscar Sterco (1977) Ltd.	Coal Valley	surface	thermal	Coal Valley	Pembina River
Gregg River Resources Ltd.	Gregg River	surface	metallurgical	Gregg River	McLeod River

estimate when they will come into operation. All coal produced by the five active mines is bituminous and goes to either thermal or metallurgical markets.

Water handling procedures are similar in outline at each of the operations, although naturally there are differences in detail from mine to mine. All process and wash water goes to a tailings pond. Current guidelines call for no discharge from tailings except in the event of a 20 year return period, 24 hour duration storm, so that 100% recycle of tailings water is the industry norm. Mine water may be directed to tailings or to settling ponds, the latter option being more common. Surface water runoff from areas within the lease but outside the mining operation is normally directed to settling ponds prior to discharge, although in some cases it is routed to tailings. Flocculants are commonly used to enhance the rate of settlement when necessary but pH control is generally not required. Under current guidelines, settling pond discharges are subject to limitations on total suspended solids (TSS), pH, and total iron. The water quality guidelines are waived for a 48-hour period following a 10 year return period, 24 hour duration storm.

Although water handling procedures are similar at each mine, there are significant differences between mines in volumes and quality of surface runoff waters, and in the background water quality of receiving streams. These differences generally result from the relative location of each mine within a watershed. For mines in the upper portion of a watershed, the mined area may approximate the total surface runoff to the receiving stream. Mine runoff may represent only a small percentage of total flow in the receiving stream for mines lower in the watershed and adjacent to large rivers.

1.3 Purpose and Objectives

The general purpose of the study was to establish the rationale for the existing wastewater discharge legislation for coal mines in the East Slopes of Alberta.

The specific objectives of the study were to document the source and basis for each parameter specified below:

1) Total Suspended Solids;
2) pH;
3) Total Iron;
4) Design flows:
    a) Water Resource Standards and Dam and Canal Safety Guidelines;
    b) 10 yr, 24-hr precipitation event exemption for effluent water quality standards;
    c) 48-hour exemption from standards for effluents from settling ponds, after a 10 yr, 24-hr. storm occurs; and
    d) the "no-discharge" requirement for tailings water and plant site surface runoff and the exceptions thereto.

It should be noted that the guidelines reviewed are not specific to East Slope mining operations; however, the recommendations made in this report apply only to East Slope mines. Environmental conditions at prairie surface mines are sufficiently different that some differences in guidelines may be required.

1.4 Data Sources

The information used in preparation of this report was gathered from the following sources:

1) available world scientific literature, including a list of relevant recent (1980 to present) publications obtained by computer search of the Aquatic Sciences and Fisheries Abstracts database;
2) federal (Canada and U.S.A.), Alberta, British Columbia, Yukon Territory, and Alaska legislation, water quality guidelines, and other relevant government documents, both published and unpublished;
3) water quality data provided by NAQUADAT, Alberta Environment, and the East Slope coal companies; and
4) conversations with coal company personnel and provincial, state and federal government personnel.

2.0 WATER QUALITY GUIDELINES

2.1 Total Suspended Solids

Suspended solids are in theory all non-dissolved materials in a water sample. In practice, the cut-off between dissolved and suspended materials is determined in the laboratory by filtration of the sample; total suspended solids (TSS) is therefore commonly referred to as non-filtrable residue (NFR). TSS or NFR, then, is a measure of the particulate material suspended in a water sample that will not pass through a designated filter. Alberta Environment uses 0.4 microns as the standard filter pore size for determining TSS (Nahulak, pers. comm.).

Total suspended solids can be subdivided into settleable and non-settleable solids. The settleable solids concentration of a water sample is defined as the volume of particles that will settle to the bottom of the water column within an Imhoff cone (volume, one litre) during one hour of quiescent settling. The settleable solids test in practice provides a measure of the concentration of solids greater than about 10 microns in diameter (Monenco 1986); colloidal solids so small that they remain in suspension due to Brownian motion are not included. The settleable/non-settleable distinction is significant because the two fractions have different impacts on aquatic ecosystems.

2.1.1 Environmental Range

In the East Slopes, suspended sediment concentrations vary considerably on an annual basis. Typically, TSS levels are low during fall and winter, rise through spring to a summer peak coinciding with the snowmelt season, and then decrease again in late summer. Shorter-term variations in TSS are normally associated with precipitation events. TSS concentrations may also vary considerably from watershed to watershed in response to variables such as water source (e.g. glacial or non-glacial), size of watershed, precipitation patterns, local relief, and land use.

NAQUADAT water quality data provide limited information for the main East Slope streams affected by coal mining. These data do not give a good estimate of TSS maxima, however, as they are based on relatively few samples. The Water Survey of Canada sediment data are based on continuous sampling and therefore provide a much better picture of sediment maxima; however, they are not available for most of the streams affected by coal mining. The NAQUADAT and Water Survey sediment data indicate that small and medium sized streams in the coal mining areas normally have TSS minima of near 0 and maxima ranging from less than one hundred to a few hundred milligrams per litre. This is supported by water quality monitoring data provided by Alberta Environment and the coal companies which indicate that background TSS concentrations in the immediate vicinity of the coal mining operations range from 1 to about 600 mg/L.

2.1.2 Effluent Range

TSS concentrations in settling ponds are routinely monitored by Alberta Environment and the coal companies. The monitoring data show a wide variety in pond performance, as would be expected. Of 15 settling ponds for which data were examined during this study, 2 had TSS maxima of less than 100 mg/L and 7 had maxima of less than 250 mg/L. On the other end of the scale, four had maxima exceeding 1,000 mg/L. The extremes of TSS concentration recorded in the data for settling ponds were 1 and 1,430 mg/L.

2.1.3 Guidelines

The current Alberta coal mining wastewater effuent guidelines are 50 mg/L or 10 mg/L above background concentration, whichever is larger. The guidelines do not apply when a rainfall event larger than the 10 year, 24 hour storm occurs.

Other current TSS guidelines are quite different, both from the Alberta guideline and from each other. The Canadian federal guideline for protection of freshwater aquatic life is 25 mg/L. In British Columbia, the objective level is 25 mg/L in sensitive aquatic systems ranging up to 75 mg/L in the less sensitive systems, with

variances being allowed "during periods of excess runoff", which may include events smaller than the 10 year, 24 hour storm. The U.S. EPA standards are 70 mg/L for a one-day maximum and 35 mg/L for a 30-day average. During periods when discharges are increased by precipitation or equivalent snowmelt volumes less than the 10 year, 24 hour event, a one day maximum standard of 0.5 ml/L settleable solids replaces the normal TSS standards. When the 10 year, 24 hour storm (or equivalent snowmelt) event is exceeded, both TSS and settleable solids requirements are waived. In Alaska, the EPA limitation is supplemented by a state requirement that the content of sediments in the 0.1 to 4.0 mm size range in spawning gravel beds not be increased by more than 5% by weight over natural conditions. In the Yukon Territory, placer mining operations are restricted to sediment discharges of 100 mg/L in waterbodies of moderate biological importance and 1,000 mg/L in waterbodies of low biological importance. No sediment discharge is allowed into waterbodies of high biological importance (Canada Department of Fisheries and Oceans 1983). Biological importance is based upon the species of fish found in a waterbody plus the life-cycle phase of the various species.

2.1.4 Source of Parameter Specification

The Alberta coal mining effluent guideline for TSS is related to the U.S. EPA limitations of 70 mg/L for a daily maximum and 35 mg/L for a 30-day average; an intermediate value of 50 mg/L was selected as a maximum value for Alberta (Johnson, pers. comm.).

2.1.5 Validation Data

The effects of suspended sediment on aquatic life have been extensively researched and several comprehensive reviews of the literature on this topic have been prepared (e.g. Cordone and Kelley 1961, Shelton and Pollock 1966, Gammon 1970, Sorensen et al. 1977, Langer 1980, Alabaster and Lloyd 1982, Canada Department of Fisheries and Oceans 1983). The major effects of suspended sediment on aquatic systems are briefly summarized below; the results of some of the more pertinent quantitative studies are presented in Tables 2.1 and 2.2.

Table 2.1 **Effects of suspended solids on aquatic life.**

Researchers	Date	Organism	Concentration (mg/L)	Type of Solids	Effects
Le Gore and Des Voigne	1973	coho salmon fry	28,000	harbour sediment	No adverse effects in 4 days
Griffin	1938	salmonid fingerlings	300-750	suspended sediments	3-4 week survival in continuous, periodic exposure
		salmonid fingerlings	2300-6500		
Herbert and Merkens	1961	rainbow trout	5000-300,000	mineral solids	1 week survival; gill damage
Herbert and Wakeford	1962	rainbow trout	4250	gypsum	50% mortality in 3 1/2 weeks
Herbert and Richards	1963	rainbow trout	200	coal washery solids	100% survival over 10 months
Sykora et al.	1972	juvenile brook trout	24-96	suspended $Fe(OH)_3$	25-84% reduction in weight compared to controls
Herbert et al.	1961	trout	60	mineral solids	normal trout population density
Peters	1957	trout	70	agricultural origin solids	slightly reduced numbers
Scullion and Edwards	1980	brown trout	100	coal industry solids	reduction in population size and condition factors
Noggle	1978	coho salmon fry	100	suspended sediments	45% reduction of feeding
			300	suspended sediments	cessation of feeding
			1200-35,000	suspended sediments	seasonal variation in LC_{50}
			4000	suspended sediments	threshold of avoidance response
Langer	1980	chum salmon eggs	12% increase	suspended sediments	55% decrease in egg survival
Campbell	1954	salmonid eggs	1000-2500	suspended sediments	100% mortality
Stephan	1953	invertebrates	300	clay	critical concentration to be harmful
		invertebrates	500	sand and loam	critical concentration to be harmful
Robertson	1957	Daphnia magna	1458	pond sediment	lethal concentration
			102	montmorillonite clay	lethal concentration
Herbert et al.	1961	invertebrates	60	mineral solids	no decrease in abundance compared with clear stream
Gammon	1970	aquatic insects	40 over natural	mineral solids	25% increase in insect drift
		aquatic insects	80 over natural	mineral solids	90% increase in insect drift
Lewis	1973	aquatic moss	100	coal dust	severe abrasive leaf damage

Table 2.2 Reported status of freshwater fisheries related to the TSS concentration (mg/L) (from Alabaster and Lloyd, 1982).

Reported status	Type of solids	Concentration range
Fish absent or fishery severely harmed	coal mining or washing	600 - 800
	china-clay mining	1000 - 10,000
	granite crushing	190 - 12,000
	metal mining	80 - 500
Fish present fishery apparently unharmed	coal washing	up to 450
	gravel washing	up to 55
	stone working	up to 60
	from driving tunnel	up to 150
	china-clay mining	up to 55
	naturally occurring solids	up to 50

The effects of suspended sediment on aquatic life can be divided into those that occur in the water column and those that occur due to accumulation of sediments in or on the substrate. Both types of effects are of concern in each of the three main divisions of aquatic life: aquatic plants, invertebrates, and fish.

The overall effect of increased suspended solids concentrations on algae and other aquatic plants is one of decreased production. This decrease in primary productivity largely results from decreased light availability due to increased turbidity, although scouring damage by sediment particles and smothering of the substrate are also contributing factors in some cases.

Benthic invertebrates are adversely affected by any reduction in primary production, as this constitutes a reduction in their food supply. Increased concentrations of suspended sediments also increase the rate of invertebrate drift, thereby contributing to the depopulation of the affected area; if the concentration is high enough, invertebrates can be directly damaged or killed. The desirable species of invertebrates (i.e. those utilized by fish) live in the interstitial spaces in gravel beds, and so they are severely affected or eliminated when sedimentation fills these spaces. Sedimentation can also cause a secondary loss of food supplies for benthic invertebrates by burying organic detritus.

These are four main ways in which an excessive concentration of suspended solids can be harmful to fish (Alabaster and Lloyd 1982, Table 2.1). These are:

1) Reduction of available food. Benthic invertebrate populations, a major food source for fish, are adversely affected by high suspended sediment loads.

2) Modification of natural behaviour. High concentrations of suspended solids interfere with feeding. When concentrations become high enough, feeding may cease altogether.

3) Direct action on fish within the water column. At high enough concentrations, suspended solids are lethal to fish, the mechanism being gill damage and eventual suffocation. The concentration at which mortality occurs varies with the type of material, with the species of fish, and, for at

least one species, with the season. Lower concentrations of suspended solids can cause lowered growth rates and increased disease susceptibility.

4) Interference with the successful development of eggs and alevins. Salmonid populations are extremely sensitive to deposition of fine materials (sedimentation) in the gravels they use for spawning. If sedimentation occurs prior to spawning, fish will avoid the affected areas (Stuart 1953, Snyder 1959); if it occurs after spawning, the egg to fry survival ratio will be reduced, often to zero or near zero. Eggs are vulnerable to sedimentation because when the interstitial spaces they occupy are clogged with fine materials, the flow of water and hence the supply of oxygen are reduced or cut off. After any surviving eggs hatch, further mortality will occur if the alevins are trapped by fine sediments and unable to reach the open water column.

Alabaster and Lloyd (1982), on the basis of their comprehensive review of the literature, have concluded that with respect to chemically inert solids:

a) There is no evidence that concentrations of suspended solids of less than 25 mg/L have any harmful effects on fisheries.

b) It should usually be possible to maintain good or moderate fisheries in waters which normally contain 25-80 mg/L suspended solids; other factors being equal, however, the yield of fish from such waters might be somewhat lower than from those in category a).

c) Waters normally containing from 80-400 mg/L suspended solids are unlikely to support good freshwater fisheries, although fisheries may sometimes be found at the lower concentrations within this range.

d) At the best, only poor fisheries are likely to be found in waters which normally contain more than 400 mg/L suspended solids.

It should be noted that these categories apply to normal (i.e. average) suspended sediment concentrations. Presumably the same concentrations would have less effect in waterbodies where they occurred only occasionally.

An important point to be recognized is that the settleable fraction of suspended solids, being responsible for sedimentation effects as well as for water column effects, has a greater effect on receiving streams than the non-settleable fraction, which passes through without deposition. Unfortunately, the existing research has generally failed to recognize this distinction. Also, not all types of suspended solids are equally harmful, but an adequate method of setting standards for individual solid types has not been established (Alabaster and Lloyd 1982).

2.1.6 Adequacy of Alberta Guideline

In terms of environmental protection, the existing guideline, which is for maximum TSS concentrations, is probably adequate, as it falls near the middle of the 25-80 mg/L range considered to be compatible with the maintenance of good or moderate fisheries. There are no East Slope studies that directly confirm the adequacy of this range, however. On the other hand, in view of the evident likelihood that settling pond effluents of a given TSS concentration have a lower proportion of settleable solids than do natural stream suspended solids loads of the same concentration, the existing standard may actually be lower than necessary for a maximum value. New field research to determine TSS/settleable solids relationships, as well as careful analysis of existing water quality data to determine long term average TSS emissions from settling ponds, would be required to determine if any upward revision of the guideline can be justified biologically. The existing guideline does appear to fall short by setting no requirements for average TSS concentrations.

Although it could be argued that a biological criterion should be measured in the receiving stream, this is difficult to do in the case of TSS. The mixing zone concept is not applicable because it fails to take into account sediments deposited within the mixing zone; quantification of actual sediment deposition in sensitive areas (e.g. the Alaska state requirements), while theoretically attractive, would

pose major problems in practice due to the difficulty of obtaining truly representative samples of substrate materials.

In terms of the practicalities, coal mine operators state, and the water quality data confirm, that variances can occur during rainfall or snowmelt events smaller than the 10 year storm, even if flocculants are used. This can easily be understood by examining the American experience with coal mine settling ponds. The initial 1976 EPA standards called for maximum and 30-day average TSS concentrations of 70 and 35 mg/L, respectively, except in the event of a 10 year, 24 hour storm or equivalent snowmelt runoff. These limits were proposed as the lowest concentrations economically achievable at coal mines. It was thought at the time that flocculation could be used to achieve compliance for rainfall events smaller than the 10 year storm; however, this proved not to be true. Both Kathuria et al. (1976) and Poe et al. (1983) found that sediment ponds designed according to the required standards did not meet the effluent limitations for some flows less than the 10 year storm event, and Ettinger and Lichty (1979) showed theoretically that the limitations could not be met in any reasonable size of basin. Thus it is to be expected that Alberta operators, faced with an even lower effective maximum limit of 50 mg/L (the background plus 10 mg/L provision appears to be of very little help in achieving compliance), will have even more difficulties in meeting the guidelines. The EPA eventually solved its non-compliance problem by setting an alternative settleable solids criterion of 0.5 ml/L that can be used for rainfall or snowmelt events smaller than the 10 year storm. The alternative requirement was based on studies showing that settleable solids can be consistently controlled in these circumstances even when TSS cannot (U.S. EPA 1982).

2.1.7 Recommendations

Section 2.1.6 makes it clear that some revision in the existing TSS guideline is reasonable for East Slopes coal mines. The problem will be to establish guidelines that are both biologically defensible and practically achievable. The development of guidelines covering average TSS concentrations, and/or alternative settleable solids guidelines, appear promising in this respect. We recommend, as a necessary

first step in revising the existing guideline, that the following research be carried out:

1) A field and laboratory study program to examine the relationship between settleable solids and total suspended solids in settling pond effluents and natural streams.

2) Quantitative field and laboratory studies differentiating the effects on aquatic systems of settleable solids from those of non-settleable solids, in light of the results of study 1).

2.2 pH

pH is a measure of the hydrogen ion activity in a water sample and provides information on the balance of acids and bases. pH is measured on a scale of 0 to 14. A value of 7 indicates chemical neutrality, values less than 7 indicate acidity, and values greater than 7 indicate alkalinity.

2.2.1 Environmental Range

In natural fresh waters pH is normally controlled by the carbonate-bicarbonate system and falls into the range 4-9 (McNeely et al 1979). NAQUADAT data indicate that pH values in the watersheds of interest are mildly alkaline, ranging from 7.4 to 8.6. These values are a reflection of East Slopes bedrock chemistry. Alberta Environment and coal company monitoring data from the mining areas indicate a wider background pH range of 6.5 to 8.8.

2.2.2 Effluent Range

Since settling pond effluents are primarily runoff from disturbed soil and bedrock materials, the range of pH is similar to the range in natural waters. Data from Alberta Environment and the coal companies indicate that settling pond pH values normally range from 6.6 to 8.9. A single anomalously high value of 10.3 has been recorded.

2.2.3 Guidelines

The Alberta Coal Mining Wastewater Effluent Guidelines call for pH to be restricted to the range 6.5 - 9.5. Some other current pH guidelines are listed below.

Alaska Water Quality Standard for Growth and Propagation of Aquatic Life	6.5-9.0
Alberta Surface Water Quality Objective	6.5-8.5
B.C. Mining Objective	6.5-8.5 to 10
Environment Canada Guideline for the Protection of Freshwater Aquatic Life	6.5-9.0
U.S. EPA Alkaline Mine Drainage Effluent Limitations	6.0-9.0

The range in the B.C. objectives is to provide latitude for variation in individual water license requirements, depending upon the sensitivity of the receiving environment.

2.2.4 Source of Parameter Specification

The Alberta objectives for pH were not established from any single documented source but rather from a general consensus of opinion in Alberta Environment that pH levels within the above mentioned range would not adversely affect aquatic life (Johnson, pers. comm.).

2.2.5 Validation Data

According to EIFAC (1969), "There is no definite pH range within which a fishery is unharmed and outside which it is damaged, but rather there is a gradual deterioration as the pH values are further removed from the normal range". Ellis (1937), in a study of 409 sites, found healthy fish populations in waters of pH 6.3 to 9.0. Doudoroff and Katz (1950), in a careful review of the then available world literature, concluded that under otherwise favorable conditions pH values between 5.0 and 9.0 are not lethal to fish. More recently, Thurston et al. (1979) made a comprehensive review of world literature and concluded that

> "the hundreds of studies published since then (1950) have offered nothing to contradict these statements (of Doudoroff and Katz)... Based on present evidence, a pH range of 6.0 to 9.0 appears to provide complete protection for the life of freshwater fish species and bottom-dwelling invertebrate fish food organisms which are of interest to most people, provided cations and anions whose toxicity is pH-dependent are absent in concentrations which may be lethal."

A search of world literature from 1980 to date conducted during the present study revealed no new research to modify these findings.

The results of some studies on the effects of pH on aquatic life are presented in Table 2.3 and summarized in Table 2.4. Studies on the effects of low pH are not included because they are not applicable to operational East Slopes coal mines. The study by Daye and Garside (1976), which showed physiological damage to brook trout beginning at pH 9.0, is particularly worthy of note.

It appears that there are no local studies of the effects of pH on aquatic organisms; however, there is no reason to believe that the results of studies conducted elsewhere are not equally applicable in Alberta's East Slopes.

2.2.6 Adequacy of Alberta Guideline

Available scientific data (Table 2.4) suggest that the existing upper limit of 9.5 for pH does not provide complete protection for aquatic life. The upper safe limit is commonly agreed to be 9.0. This is supported by other North American water quality guidelines, which specify an upper pH limit of either 8.5 or 9.0.

2.2.7 Recommendations

We recommend that the guidelines for pH be changed to 6.5-9.0. This recommendation is based on the following considerations:

1. pH 9.0 is specified throughout the literature as an upper safe limit.
2. The guidelines would be more consistent with other North American guidelines for pH.

Table 2.3 Effects of high pH on aquatic life.

Researchers	Date	Organism	pH	Effects
Daye & Garside	1975	brook trout	9.8	lethal limit
Daye & Garside	1976	brook trout	9.0	lower limit of tissue and cellular degeneration
McCarraher & Thomas	1968	fathead minnow	9.2-10.1	survival in lakes for up to 6 months
Eicher	1946	rainbow trout	10.2	fish kill in lake
			9.4	no fish kill in lake
Sawyer	1974	leeches	10.4	present in Colorado waters
Harman	1974	gastropods	10.3	present in natural waters
Sanborn	1945	goldfish,	10.5	all survived 7 days in flowing water
		largemouth bass,	10.9	goldfish and bass died
		bluegill	11.1	bluegills died
		goldfish	10.6	7 day survival threshold using $CaCO_3$
		bluegill	10.1	7 day survival threshold using $CaCO_3$
		largemouth bass	9.7	7 day survival threshold using $CaCO_3$
Calabrese	1969	bluegill	9.4-9.7	7.2% mortality using NaOH and tap water
		bluegill	9.7-10.3	2.5% mortality using $Ca(OH)_2$ and tap water
		bluegill	9.4-9.8	5.0% mortality using $Ca(OH)_2$ and pond water
		largemouth bass	9.4-9.7	4.5% mortality using NaOH and tap water
		largemouth bass	9.7-10.3	3.0% mortality using $Ca(OH)_2$ in tap water
		largemouth bass	9.4-9.8	7.5% mortality using $Ca(OH)_2$ in pond water
Cairns and Scheier	1958	bluegill	10.5	4 day median tolerance limit for small fish
		bluegill	9.9	4 day median tolerance limit for large fish
Bandt	1936	trout	9.2	minimum lethal value
Jordon and Lloyd	1964	rainbow trout	9.5	15-day LC_{50}
Sprague	1964	Atlantic salmon	9.5	5% mortality in 6 weeks
Carter	1964	brown trout	9.5	survival for more than 4 days in sea water
Rosseland	1956	salmon, brown trout	9.7	lethal to young fish within 1 day
Mantelman	1967	Coregonus peled	8.6-9.2	highest safe pH level
Krishna	1953	trout eggs, alevins	above 9.0	some mortality

Table 2.4 Summary of pH effects on fish (from Alabaster and Lloyd, 1982).

pH Range	Effect
6.0-6.5	Unlikely to be harmful to fish unless free carbon dioxide is present in excess of 100 mg/L.
6.5-9.0	Harmless to fish, although the toxicity of other poisons may be affected by changes within this range.
9.0-10.0	Lethal to salmonids and perch if present for a considerable length of time.
10.0-10.5	Can be withstood by roach and salmonids for short periods but lethal over a prolonged period.
10.5-11.0	Rapidly lethal to salmonids. Prolonged exposure to the upper limit of this range is lethal to carp, tench, goldfish and pike.
11.0-11.5	Rapidly lethal to all species of fish.

2.3 Total iron

Iron occurs in natural waters primarily in two forms, the ferrous (Fe^{+2}) and ferric (Fe^{+3}). Ferrous iron is relatively soluble and therefore quite mobile, but is normally present only under anaerobic or reducing conditions. When exposed to oxygen, ferrous iron oxidizes to the ferric form, which is for all practical purposes insoluble. In oxygenated water, the iron may occur in organometallic and colloidal forms and is associated with particulate matter. Because of this association the total iron content of streams tends to fluctuate with variations in suspended solids concentrations.

2.3.1 Environmental Range

The iron content of natural waters varies widely. NAQUADAT data record a background range of less than 0.02 mg/L to 1.18 mg/L in the watersheds of interest. Alberta Environment and coal company data from the mining areas indicate a wider natural variation ranging up to 11.0 mg/L total iron.

2.3.2 Effluent Range

Data from Alberta Environment and the coal companies indicate that the iron concentration in settling pond waters normally ranges from less than 0.05 to about 2.5 mg/L; however, higher values do occur occasionally. The maximum concentration recorded in the data inspected during this study was 79 mg/L. The higher concentrations of iron recorded appear to be closely related to high suspended sediment concentrations.

2.3.3 Guidelines

The Alberta Coal Mining Wastewater Effluent Guideline for iron is 3.5 mg/L, measured as total iron. Other current iron guidelines are listed below.

Alaska Water Quality Standard			None
Alberta Surface Water Quality Objective			0.3 mg/L
B.C. Mining Objective			1.0 mg/L
Environment Canada Guideline for the Protection of Freshwater Aquatic Life			0.3 mg/L
U.S. EPA Alkaline Mine Drainage Effluent Limitations:			
	24 hour maximum	7.0 mg/L	6.0 mg/L
	30-day average	3.5 mg/L	3.0 mg/L

The more stringent of the EPA limitations apply to new sources only.

2.3.4 Source of Parameter Specification

The Alberta coal mining effluent guideline was established on the basis of the then current EPA standards of 7.0 mg/L (24 hour maximum) and 3.5 mg/L (30-day average). In view of the need to protect aquatic life, Alberta Environment staff chose the more stringent of the two EPA standards as a maximum value for Alberta (Johnson, pers. comm.).

2.3.5 Validation Data

Iron in domestic water supplies can stain laundry and porcelain plumbing fixtures, as well as imparting an unpleasant taste to drinking water. The guidelines for maximum acceptable levels of iron in domestic water supplies are generally set at 0.3 mg/L in Canada and the United States.

Numerous studies of the effects of iron on aquatic life have been conducted worldwide, particularly in the United States. Ellis (1937) found that 95% of good fish producing waters had iron concentrations of 0.7 mg/L or less and that 50% had concentrations of 0.3 mg/L or less. EIFAC (1964) and U.S. EPA (1976a) recommended a guideline of 1.0 mg/L to protect aquatic life, based on reviews of available data. More recently McNeely et al. (1979) recommended 0.3 mg/L on

the basis of studies by the Great Lakes Water Quality Board (1976), while a review of literature conducted by Thurston et al. (1979) led them to conclude that 0.3 mg/L total iron may be too high for protection of aquatic life. This conclusion was based in part on studies by Warnick and Bell (1969), who found 96-hour LC_{50} values of 0.32 mg/L (i.e. half the organisms died in 96 hours at this concentration) iron for mayflies, stoneflies, and caddisflies, all of which are important fish food organisms. The few studies of iron toxicity conducted since 1980 provide no significant additional information. None of the research on iron toxicity examined during this study was specific to Alberta's East Slopes, and while there is no definite reason to believe the research is not applicable here, questions do arise (particularly with respect to laboratory studies) in terms of possible differences in water chemistry and the forms of iron present in the water column.

Another potential problem related to iron-rich water is the formation of "iron flocs", which occurs when anaerobic iron-bearing mine drainage waters or groundwaters enter oxygenated surface waters. Under these conditions, iron precipitates as ferric hydroxide, $Fe(OH)_3$, or ferric oxide, Fe_2O_3. These precipitates can be detrimental to aquatic life either when suspended in the water column or when they settle to the bottom. In time, iron flocs can consolidate to form a cemented substrate; this is particularly of concern in salmonid spawning areas which are thus rendered useless. Iron flocs may also incorporate other undesirable metals such as cadmium, chromium, copper or zinc (McFadden, pers. comm.)

The bioavailability of the different forms of iron that may be present, either in natural waters or mine wastewaters, is a topic that appears to have received very little attention in the scientific literature. Total iron may include dissolved iron, colloidal iron precipitates that may or may not be associated with organic particulates or other suspended solids, iron complexed to organic compounds, and iron bound up in suspended mineral particles. Dissolved iron clearly is bioavailable; at the other end of the scale, iron in mineral particles clearly is not. The bioavailability of other forms of iron appears to be largely unknown. This is of interest because the proportions of the different forms of iron making up the total iron content of a water can vary widely. Practical laboratory experience (Laberge, pers. comm.) indicates that the higher the total iron content,

the lower the proportion of the total formed by dissolved iron and extractable iron (Extractable iron is a measure of iron obtained from a sample using a cold, dilute acid leach; it is sometimes taken to be a measure of bioavailable iron. Total iron, by comparison, is measured using a concentrated acid digestion technique). This is often because high concentrations of total iron are associated with high concentrations of suspended solids, with a large proportion of the iron content bound up in mineral particles.

2.3.6 Adequacy of Alberta Guidelines

The available literature indicates that the existing iron guideline is potentially too high to protect aquatic life adequately. Whether or not this is actually true is not certain, considering the dilution factor in receiving streams, the periodically high background iron concentrations in the watersheds of interest, and the relative bioavailability of high concentrations of total iron; however, it certainly may be. Whatever the case the existing guideline cannot be justified in terms of protecting aquatic life. It should be pointed out, however, that the Alberta guideline was not based on ecological considerations but on the U.S. EPA coal mining effluent limitations, which are pragmatic limits based on study of the best effluent reductions that are practical within an economically realistic scenario. The EPA limitations are considered to be equally applicable for all mines in the alkaline drainage category (the category into which the Alberta mines would fall), regardless of topographic and climatic variations. Assuming the EPA work to be substantially correct, and assuming that the economics of coal mining are not substantially better in Alberta then in the USA, it follows that the existing Alberta standard for maximum iron concentrations (since it is twice as stringent as the corresponding EPA standard) cannot economically be met at all times within the current framework of allowable exceptions. Available water quality data confirm this. There appear to be no alternate studies that would support the Alberta guideline on practical grounds.

A final consideration with respect to the current Alberta guideline is the iron parameter actually being measured during routine monitoring. The guideline specifies total iron as the parameter, but Alberta Environment currently measures

a form of extractable iron instead (Nahulak, pers. comm.). In recent coal company data, iron results are variously reported as total iron, extractable iron, or iron (total or extractable not specified). Whether or not there is a discrepancy in actual laboratory procedures that matches these differences in nomenclature is unclear.

2.3.7 Recommendations and Discussion

For the sake of consistency, any discrepancy that may exist among:

1) the iron parameter specified by the guideline,
2) the iron parameter actually being measured by Alberta Environment, and
3) the iron parameter(s) being reported by the coal companies

should be rectified. This can be done without difficulty. We also recommend that research be conducted to identify the various forms of iron actually present in mine effluents and to determine their toxicity. Once adequate data are obtained, a new guideline could be drafted specifying an appropriate form of iron to be measured.

Available information indicates that the existing iron guideline may be too high from an ecological point of view and too low from a practical perspective. Therefore we cannot recommend that the existing guideline either be raised, lowered, or retained without change. A change in the direction of protecting aquatic life, although it might appear desirable, could prove cumbersome to implement. Since it is clear that the relatively low value of total iron currently considered ecologically desirable cannot always be met at settling pond outfalls, compliance would probably have to be measured in a receiving stream, presumably the nearest stream considered to be ecologically important. This would involve development of a procedure for determining reasonable mixing zones, followed by

site specific calculations, as is currently practiced in Alaska (although not for iron). It could also penalize headwater mining operations, which are forced to discharge to small streams. Such an approach, while more complex than that currently used in Alberta, may be the only method of adequately resolving the apparent conflict between environmental protection and achievable discharge limits.

3.0 DESIGN FLOWS

3.1 Dam and Canal Safety Guidelines

3.1.1 Current Guidelines

Settling and tailings ponds in Alberta are licensed under the Water Resources Act. Draft Guidelines for Administration of Surface Water for Mining Developments in Alberta (Alberta Environment 1984) are used to define the information required for a license application for ponds of all sizes. The guidelines provide few specific design criteria with the exception of "a service outlet (if required) designed on the basis of an economic analysis with a 1:20 year peak discharge event as the minimum criteria", and a "spillway (either service and/or emergency) designed to convey at least the 1:100 year peak discharge". Coal mine tailings ponds and settling ponds with storage capacities of 60 dam^3 (approximately 50 ac-ft.) or greater must comply with the 1983 Dam and Canal Safety Regulations as described in Guidelines developed by the Dam Safety Branch (Alberta Environment 1983). The guidelines provide design standards for dams of varying heights, storage capacities, and hazard potential. Tables 3.1 through 3.3 list the criteria by which these design standards are currently determined. As shown in Table 3.3, design standards are defined primarily in terms of the probable maximum flood (PMF). The PMF, put simply, is an estimate of the largest flood that could possibly occur at a given location owing to natural circumstances.

Dam safety is within provincial jurisdiction in Canada and state jurisdiction in the United States, so that no federal dam safety guidelines exist in either country. No other province, and virtually no states, have dam safety legislation comparable with Alberta's (Anderson, pers. comm.). In British Columbia, coal mining operations may be subject to draft guidelines for the design and operation of settling ponds at mining operations (B.C. Ministry of Environment 1980), which specify that "all structures within the settling pond system should be designed to withstand the 1 in 200 year flood". In Alaska, coal mining operations must currently comply with the Alaska Surface Coal Mining Program (Alaska

Table 3.1 Dam size classification[a]

Category	Storage (dam^3)	Height (m)
Small	60 to 1,000	below 12
Intermediate	1,000 to 50,000	12-30
Large	Over 50,000	Over 30

a. To classify a dam use the value of height or storage that gives the larger size category.

Table 3.2 Dam hazard potential classification

Category	Loss of Life (Extent of Development)	Economic Loss (Extent of Development)
Low	None expected (no permanent structures or habitation downstream)	Minimal (undeveloped to occasional structures or agriculture)
Significant	Few (no urban developments and no more than a small number of inhabitable structures)	Appreciable (notable agriculture, industry or structures)
High	More than a few (permanent village or urban development)	Excessive (extensive industry or agriculture)

Table 3.3 Recommended design flood

Hazard Potential	Size Classification		
	Small	Medium	Large
Low	100 yr.	100 yr to 0.5 PMF	0.5 PMF
Significant	100 yr to 0.5 PMF	0.5 PMF	0.75 PMF
High	0.5 PMF to PMF	PMF	PMF

PMF = probable maximum flood

Department of Environmental Conservation 1985), which has an open-ended requirement that sediment ponds (including tailings ponds) be able to "safely discharge the peak 25 year, 24 hour runoff event or larger event specified by the commissioner based on... local conditions...".

3.1.2 Source of Specification

The existing Alberta guidelines represent a modification of standards first developed by the Dam Safety Branch in 1978. As no appropriate work had been done in Canada at the time, the 1978 standards were based on a review of design criteria in use elsewhere, particularly those of the U.S. Corps of Engineers and the British Institute of Civil Engineers, which represented the "state of the art" at that time (Anderson, pers. comm.).

3.1.3 Validation Data

Guidelines such as the current dam safety guideline cannot be validated in terms of scientific research; rather, they must reflect the level of risk deemed acceptable by the responsible government agency. The current Alberta guidelines take geographic location into account in the hazard potential classification (Table 3.2) and therefore are as applicable to remote coal mines as to any other development.

3.1.4 Adequacy of Alberta Standard

The Dam Safety Branch currently feels that the existing guidelines are too conservative; i.e., that the levels of risk represented by at least some of the design criteria are unnecessarily small (Anderson, pers. comm.). The Branch is therefore working toward legislative changes that will result in some deregulation and softening of standards. The current size classification system will be modified such that many dams will fall into smaller size categories or will no longer be subject to the guidelines. Under the new system, any dam with a

storage capacity of less than 25 dam^3 (20 ac-ft) on with a height of less than 2.5 m will not be covered by the guidelines (Anderson, pers. comm.). Changes are also likely to be seen in the design criteria themselves, as PMF is now considered an unnecessarily stringent standard unless the hazard evaluation includes possible loss of life. The probability that a PMF event will occur is, of course, vanishingly small; even a 0.5 PMF event has a probability of substantially less than 1 in 10,000, when estimated using current methods (Anderson, pers. comm.). The proposed changes would benefit coal companies having to construct new settling ponds because more ponds would fall into relatively "soft" design criteria categories.

3.1.5 Recommendations

With the Dam Safety Branch currently working toward revisions in the Dam and Canal Safety Guidelines, it appears to be an opportune time for the coal industry to provide input.

3.2 Precipitation Exemption from Water Quality Guidelines

3.2.1 Current Guidelines

The Alberta coal mining effluent guidelines for TSS, pH, and iron are currently waived in the event of a 10 year, 24 hour storm being exceeded on the mine site.

Licenses currently state the amount of rainfall (mm/24 hours) which equals the 10 year, 24 hour storm event for each mine site. Rain gauges capable of recording rainfall at 15 minute intervals are also required.

In British Columbia, the pollution control objectives applicable to coal mining (B.C. Ministry of Environment 1979) allow for variances in TSS during periods of "excess runoff". No specific storm magnitude is set out, although the draft guidelines for settling pond design (B.C. Ministry of Environment 1980) set the 10 year, 24 hour storm as the design flow for removal of suspended solids in settling ponds. State legislation in Alaska does not appear to allow for such variances. At the federal level in the United States, the EPA guidelines allow for variances in TSS and iron in the event of a 10 year, 24 hour storm. They also allow for TSS variances during less intense rainfall events by substituting a settleable solids requirement for such cases (see Section 2.1).

3.2.2 Source of Specification

The source of the current Alberta exemption from effluent water quality guidelines was the EPA exemption for 10 year, 24 hour storm events (U.S. EPA 1976b, 1976c).

3.2.3 Validation Data

Guidelines of this type strive to provide the maximum amount of environmental protection possible considering the practicalities of settling pond design, as defined by topographic and economic constraints. The 10 year, 24 hour exemption

specification has been standard throughout the United States for a decade and is also in use in British Columbia.

3.2.4 Adequacy of Alberta Guideline

The existing Alberta exemption standard is in use throughout the United States and appears to work well in combination with the water quality guidelines currently in place there. In Alberta's East Slopes, coal mine operators are frequently unable to meet TSS guidelines for precipitation events smaller than the 10 year, 24 hour storm. Several operators feel that this is due to a failure to take into account antecedent conditions (e.g. whether the watershed is dry, saturated, or somewhere in between at the onset of the storm), shorter duration but more intense rainfalls (e.g. a 25 year, 12 hour storm), and longer duration but less intense rainfalls (e.g. a 9 year, 48 hour storm). However, it would be very difficult to incorporate these variables (particularly antecedent conditions) into the guidelines, and in the U.S.A. it has not been found necessary to do so. The problem likely does not originate with the 10 year exemption specification but with the Alberta TSS guidelines, which differ substantially from the U.S. EPA guidelines, as explained in Section 2.1.3.

Another problem frequently cited by coal mine operators is that estimations of the 10 year, 24 hour storm events are based either on data from off-site stations with different (and often lower) precipitation patterns, or on insufficient on-site data. This is not a problem that could be solved by a numerical change in the guideline, however. If coal mine operators began collection of both rain and snowfall data earlier in the project planning phase, then both under and over design of settling ponds likely could be reduced substantially. Data collected in the pre-operational phase must also consider, however, the eventual effect of clear-cutting and soil removal on storm-related discharges. These activities greatly alter watershed characteristics such as infiltration, runoff rates and transpiration.

3.2.5 Recommendations

No change in the current guideline is recommended. Instead, the TSS guidelines should be reviewed as explained in Section 2.1. The collection of more complete hydrological and meteorological data for mine sites prior to operation is strongly recommended.

3.3 Duration of Precipitation Exemption

3.3.1 Current Guidelines

The coal mining wastewater effluent guidelines do not specify a duration for the exemption from water quality standards granted in the event of a 10 year, 24 hour storm. Current Alberta Environment practice is to allow 48 hours for the exemption. The duration of exemption allowable has not been formalized in British Columbia and is determined on a case-by-case basis (Schurr, pers. comm.). Current U.S. EPA practice is to allow an exemption period based on the watershed response time and settling pond retention time, to a maximum of 36 hours except in extreme cases (U.S. EPA 1983, Harder pers. comm.).

3.3.2 Source of Specification

The source of the 48 hour duration of exemption is from the U.S. EPA (Nahulak, pers. comm.).

3.3.3 Validation Data

The length of time required for settling pond operation to return to normal following a major storm is determined by the hydrological characteristics of the pond's drainage basin, mainly the pond retention time and basin response time. According to the U.S. EPA (1983), 36 hours should in virtually every case be enough time for a sediment pond to return to base flow (or close enough to base flow to allow TSS limitations to be met).

The Alberta guideline avoids the complexities of determining an appropriate duration of exception for each settling pond, instead selecting a single, relatively large value.

3.3.4 Adequacy of Alberta Guideline

The current guideline appears to allow enough time for operating conditions in settling ponds to return to base flow following a major storm, considering the small size of settling pond drainage basins. This contention is supported by the 36 hour maximum effluent water quality exemption deemed adequate in the United States. In terms of environmental protection, the duration of exemption is not overly long, provided that operators are encouraged to make every reasonable effort to control TSS emissions during the exemption period.

A weakness in the guidelines is the failure to take into account the effect of rainfall after the 10 year, 24 hour storm event. Coal operators note that such rainfall, even though much less intense than prior storms, will cause continuing exceedances of the guidelines, plus hampering efforts to reduce emissions.

3.3.5 Recommendations

It is recommended that the guidelines be changed to specify that the 48 hour duration of exemption can be extended to include the period of continuous rainfall following the 10 year, 24 hour storm event. The 48 hour duration should also be specified in the guidelines, along with a requirement for operators to provide a reasonable level of TSS emission control during the exemption period.

3.4 No-discharge Requirements and Exceptions

3.4.1 Current Guidelines

The current Alberta guidelines specify that there should be no discharge from plant site surface runoff facilities except in the event of a 10 year, 24 hour or larger storm. For tailings ponds, no discharge is allowed unless a 20 year, 24 hour or larger rainfall occurs.

The U.S. EPA currently has no-discharge requirements for process water but not for plant site surface runoff. The no-discharge requirements are waived in the event of a 10 year, 24 hour storm (U.S. EPA 1983, Harder pers. comm.). The no-discharge requirements are for new sources only; no retrofitting at existing operations has been requested.

In British Columbia, there is no official requirement for no-discharge from tailings and no standard design specification in terms of storm events for tailings dams. The B.C. government strongly encourages designs that provide for no tailings discharge, however, and this has become the industry norm (Schurr, pers. comm.). There is no requirement for no-discharge of plant site surface runoff.

3.4.2 Source of Specification

The source of the no-discharge requirements for plant site surface runoff facilities and tailings, and the precipitation exceptions thereto, have not been documented.

3.4.3 Validation Data

In 1982 the U.S. EPA promulgated a no-discharge requirement for coal mine process water at new sources, having determined in theory that this would be economically achievable at new mines for rainfall events smaller than the 10 year, 24 hour storm, regardless of topographic and climatic differences among mine

sites. No-discharge may in practice be difficult to achieve at some locations due to topographic constraints, particularly in mountainous and hilly terrain. This is reflected by amendments currently being made to the EPA requirements, which will allow for discharge from coal slurry ponds subject to water quality limitations (U.S. EPA 1985, Harder pers. comm.).

The environmental rationale behind the no-discharge requirements appears to be that tailings water may contain harmful materials not present in other mine wastewaters.

3.4.4 Adequacy of Alberta Guideline

The no-discharge guideline for plant site surface runoff has not been made a water licence requirement for existing coal mines in Alberta's East Slopes, although one mine site is currently able to conveniently direct plant site runoff to tailings, thereby achieving no-discharge. A majority of the mines, however, handle plant site runoff in the same way as all other surface runoff and discharge it with Alberta Environment's approval. This is consistent with normal practice at existing coal mines in the United States and British Columbia.

The no-discharge requirement for tailings, while achievable in theory, provides difficulty for some of Alberta's East Slopes Coal Mines; the 20 year storm design standard is seen as onerous by these operators. Natural topographic restriction of pond size is cited as an important limiting factor at the sites experiencing problems. Given the adverse topography and moderately high rainfall in Alberta's East Slopes, the 20 year storm retention design standard does appear to be unrealistically high for at least some mines, particularly as it is more stringent than corresponding standards anywhere in the United States or in British Columbia.

Some mine operators interviewed during the present study reported that since their tailings pond water quality is frequently as good as or better than the quality of water concurrently being routinely discharged from settling ponds, they perceive the no-discharge requirement as inconsistent and see no reason why clean

tailings water should not be discharged occasionally. In fact, at least two East Slopes mines have on occasion been allowed by Alberta Environment to decant clear top water from their tailings ponds, in each case to guard against possible subsequent uncontrolled discharges. From an environmental protection point of view this makes good sense, as the aquatic impacts of making periodic controlled discharges of tailings water, provided that appropriate water quality criteria are met, are probably very small in comparison to the impacts of an uncontrolled flow of poor quality water. Such dewatering will increase the life of an individual pond and thus reduce the need for additional ponds. Tailings pond dewatering will also eventually be necessary to allow the capping and eventual reclamation of tailings ponds.

3.4.5 Recommendations

We recommend that the no-discharge requirement for plant site surface runoff be removed from the guidelines, as there is no satisfactory rationale or validation data for it. We also recommend that the existing no-discharge requirements for tailings water be amended to allow for periodic, controlled discharge of water (possibly through the surface runoff treatment system), provided that appropriate water quality standards can be met. The trade-off involved -- the certainty of small, good quality tailings discharges for a significant reduction in the risk of a large, poor quality discharge -- would make mine site stormwater management easier and thus effectively provide a higher overall degree of environmental protection than is currently in place. This change would probably necessitate the development of tailings water quality guidelines for parameters not currently measured in settling pond effluents. Site specific license requirements may also be needed in order to monitor specific chemicals used in the coal cleaning operations.

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